

## **Attachment 7.3 – Supporting Documents**

### **Economic Analysis – Water Supply Costs and Benefits**

#### **Project C - Cottonwood Creek, Berenda Creek, and Dry Creek Arundo Eradication and Sand Removal**

#### **Madera Region – IRWM Implementation Grant Application**

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## Attachment 7.3 - Evapotranspiration Calculations

### Evapotranspiration (ET) and Water Use Calculations

1	Arundo ET <sup>1</sup>	0.12	acre feet per acre per day
2	Large Bunch Grasses ET (conservative value) <sup>1</sup>	0.05	acre feet per acre per day
3	Difference in Arundo ET and Large Bunch Grass ET (1-2) <sup>1</sup>	0.07	acre feet per acre per day
4	Sunny Days per year in Madera County (when ET rate occurs) <sup>2</sup>	194	days
5	Water saved per acre per year by eradicating ET (3*4)	13.58	acre feet per year
6	Value of an acre foot of water <sup>3</sup>	\$60	
7	Value of water saved per year per acre (5*6)	\$814.80	
8	Number of acres of Arundo to be eradicated by MID <sup>4</sup>	300	acres
9	Total value of water saved per year by MID by eradicating Arundo (7*8)	\$244,440	

#### Footnotes

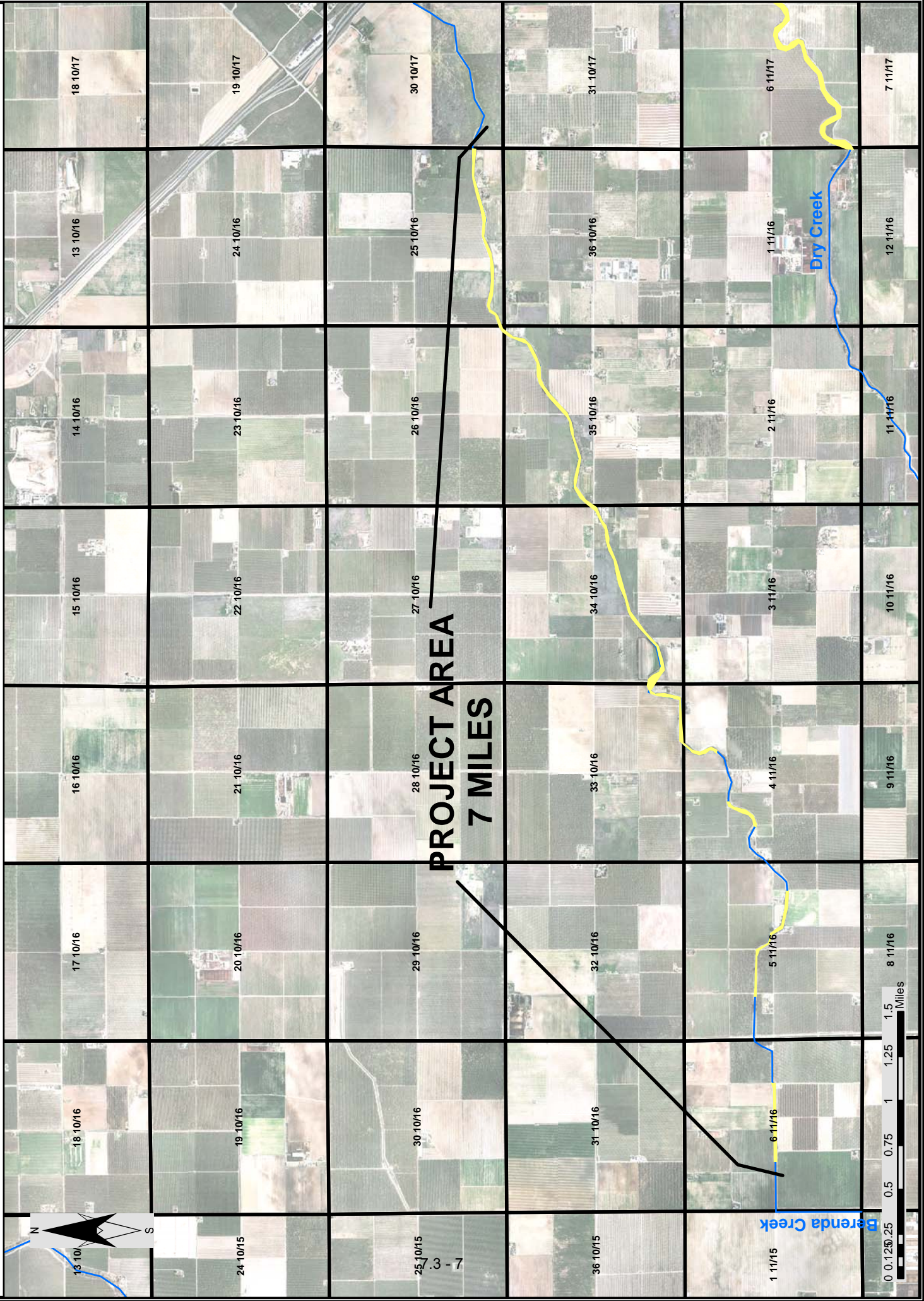
- 1 ***Preliminary Comparison of Transpirational Water Use by Arundo donax and Replacement Riparian Vegetation Types in California***, Report to Madera Co. RCD, Elissa Brown  
From: Tom Dudley, Marine Science Institute, U.C. Santa Barbara  
& Shelly Cole, Environmental Sciences Program, U.C. Berkeley
- 2 <http://www.wrcc.dri.edu/htmlfiles/westcomp.clr.html>
- 3 Madera Irrigation District's 2010 Water Rate
- 4 Cottonwood, Berenda, and Dry Creek Arundo Location Maps

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## Attachment 7.3 - Project Maps

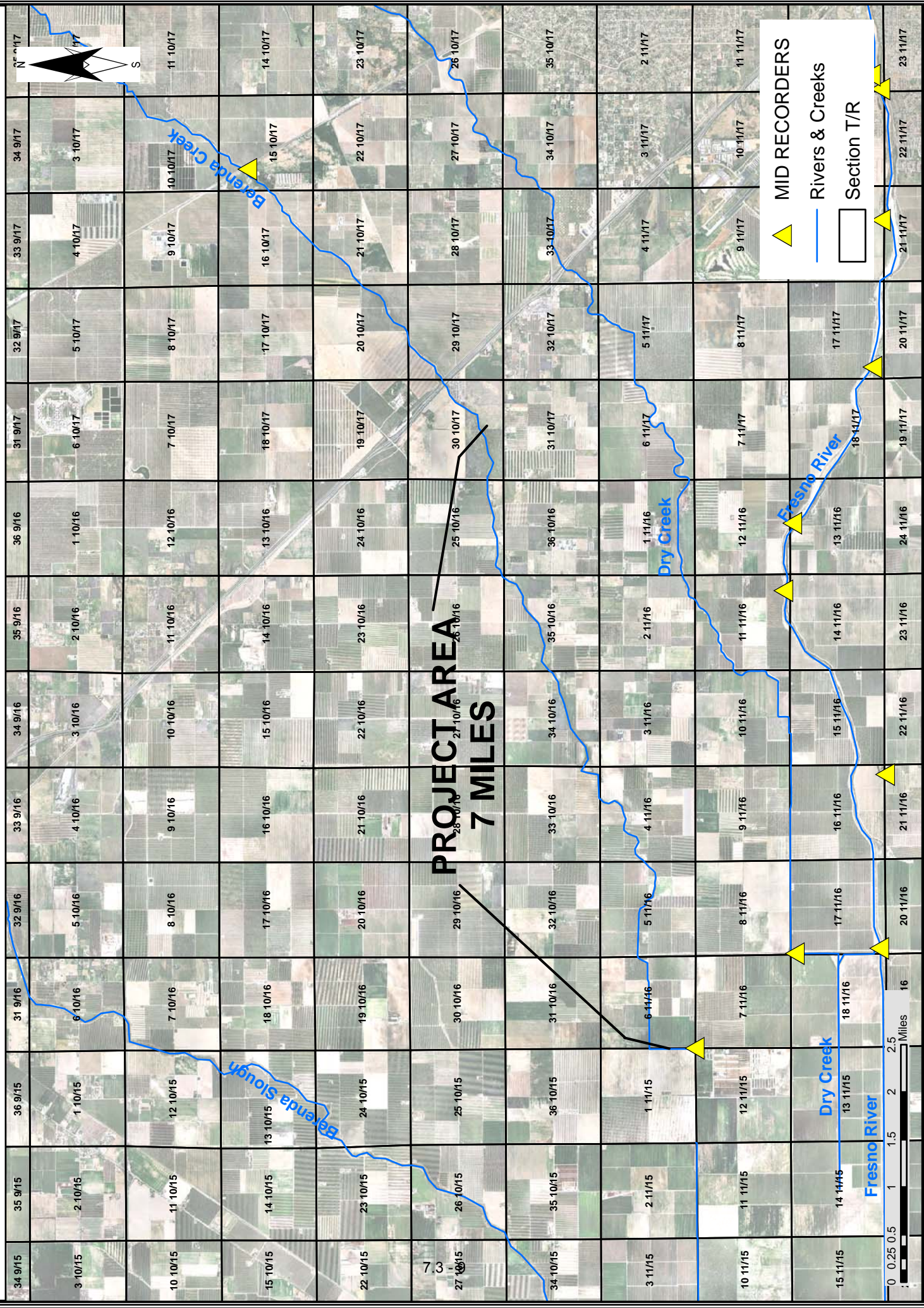
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# BERENDA CREEK ARUNDO LOCATION MAP



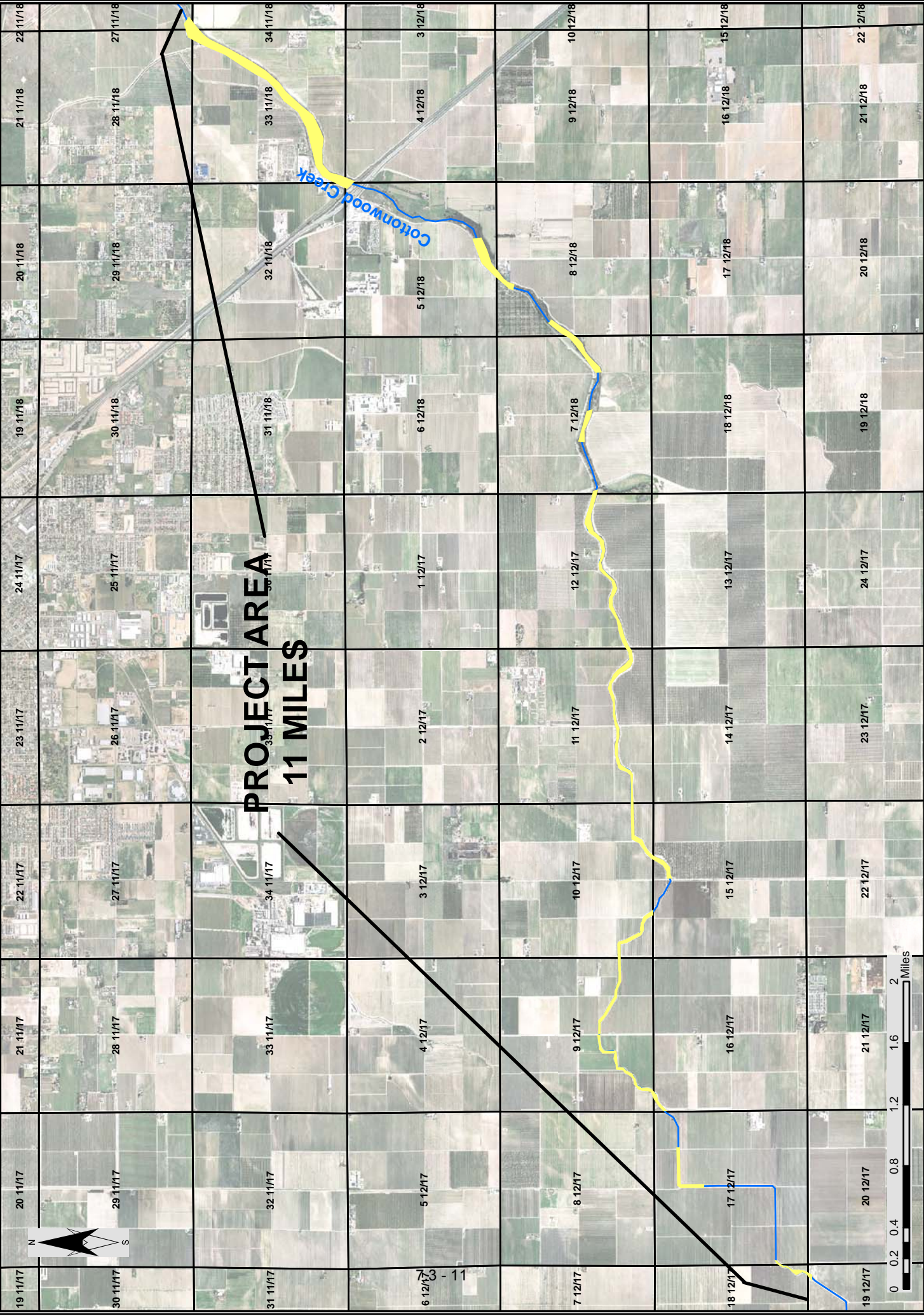
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# BERENDA CREEK RECORDER LOCATION MAP



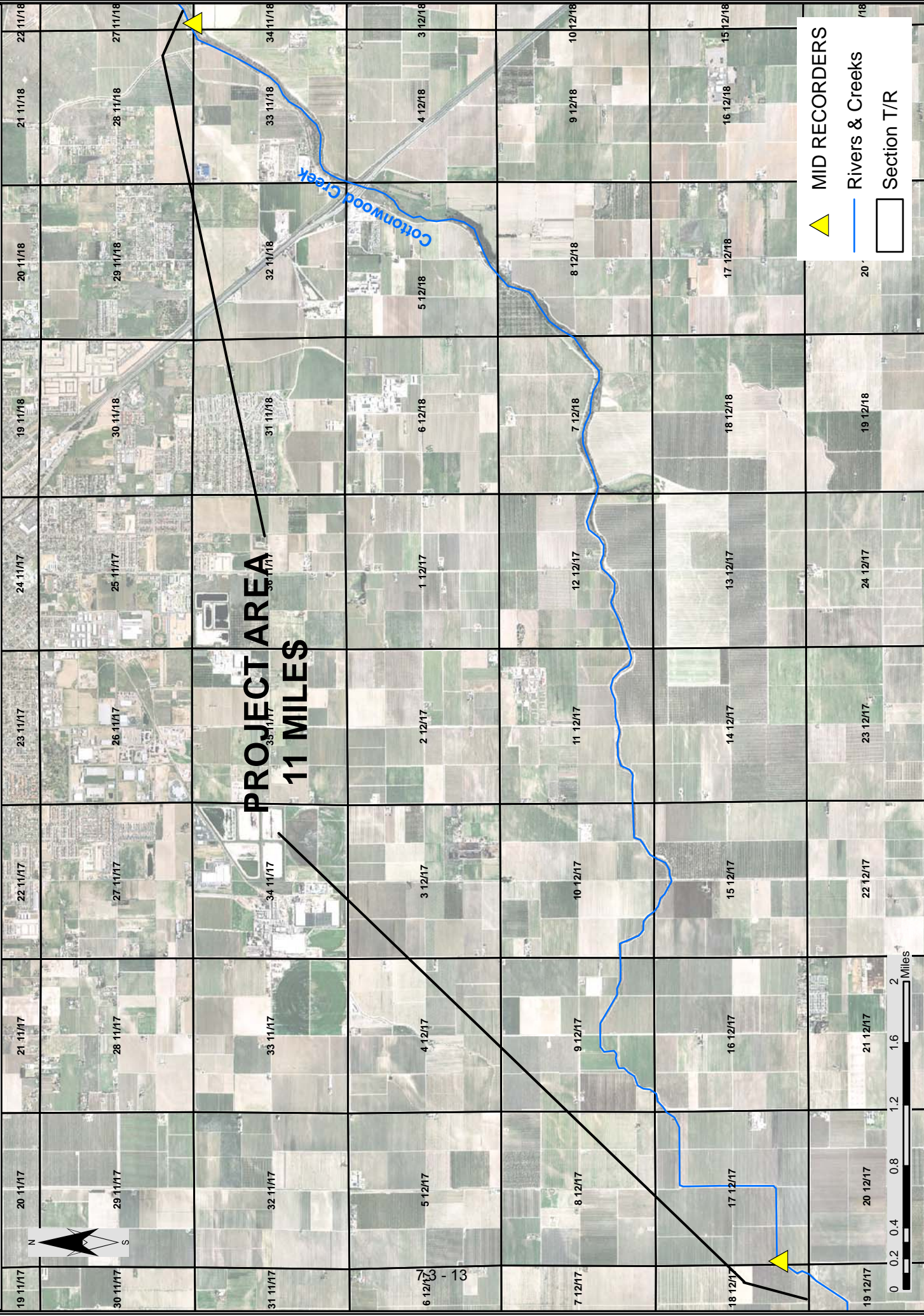
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# COTTONWOOD CREEK ARUNDO LOCATION MAP



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# COTTONWOOD CREEK RECORDER LOCATION MAP

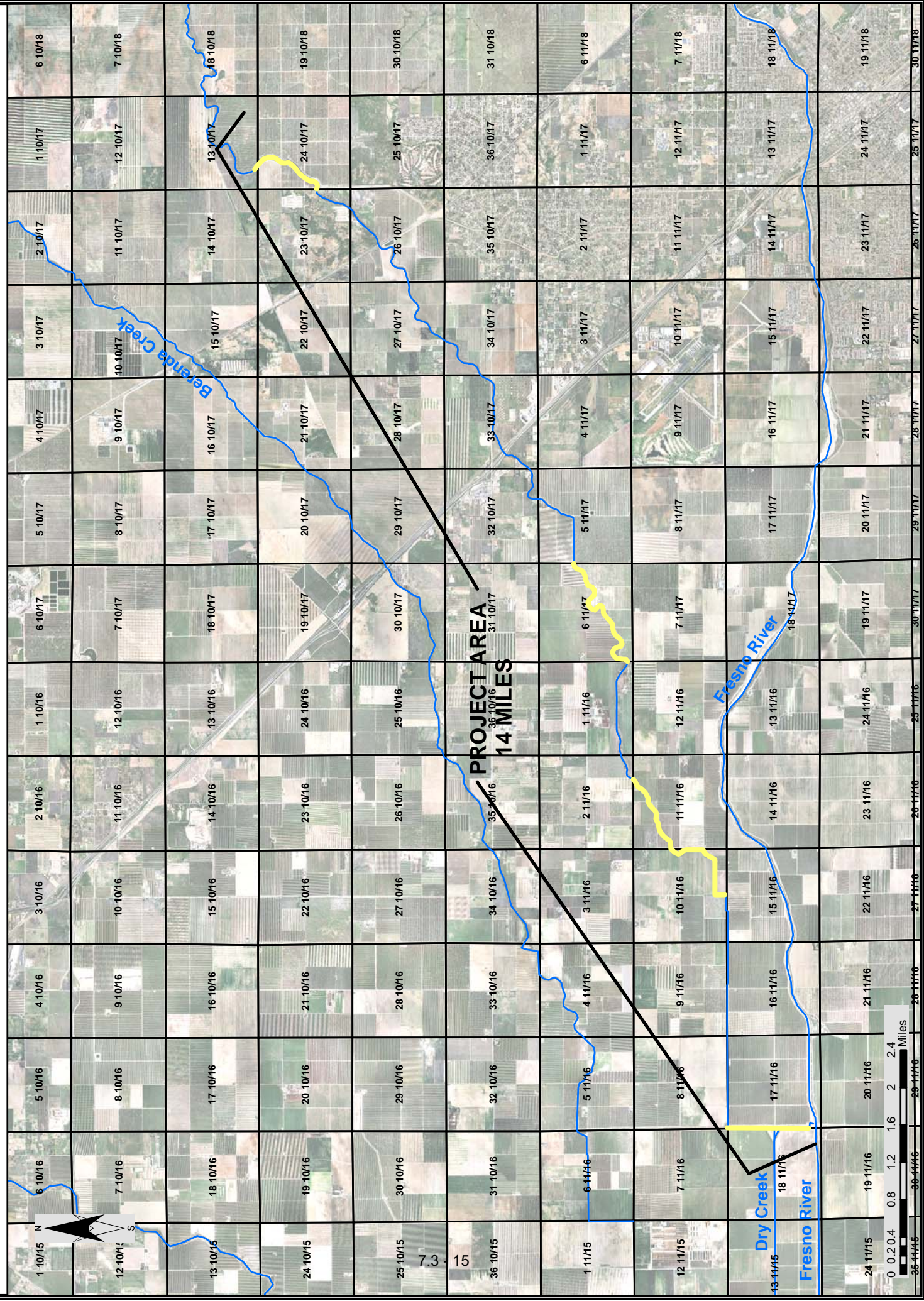


**MID RECORDERS**

- MID RECORDERS
- Rivers & Creeks
- Section T/R

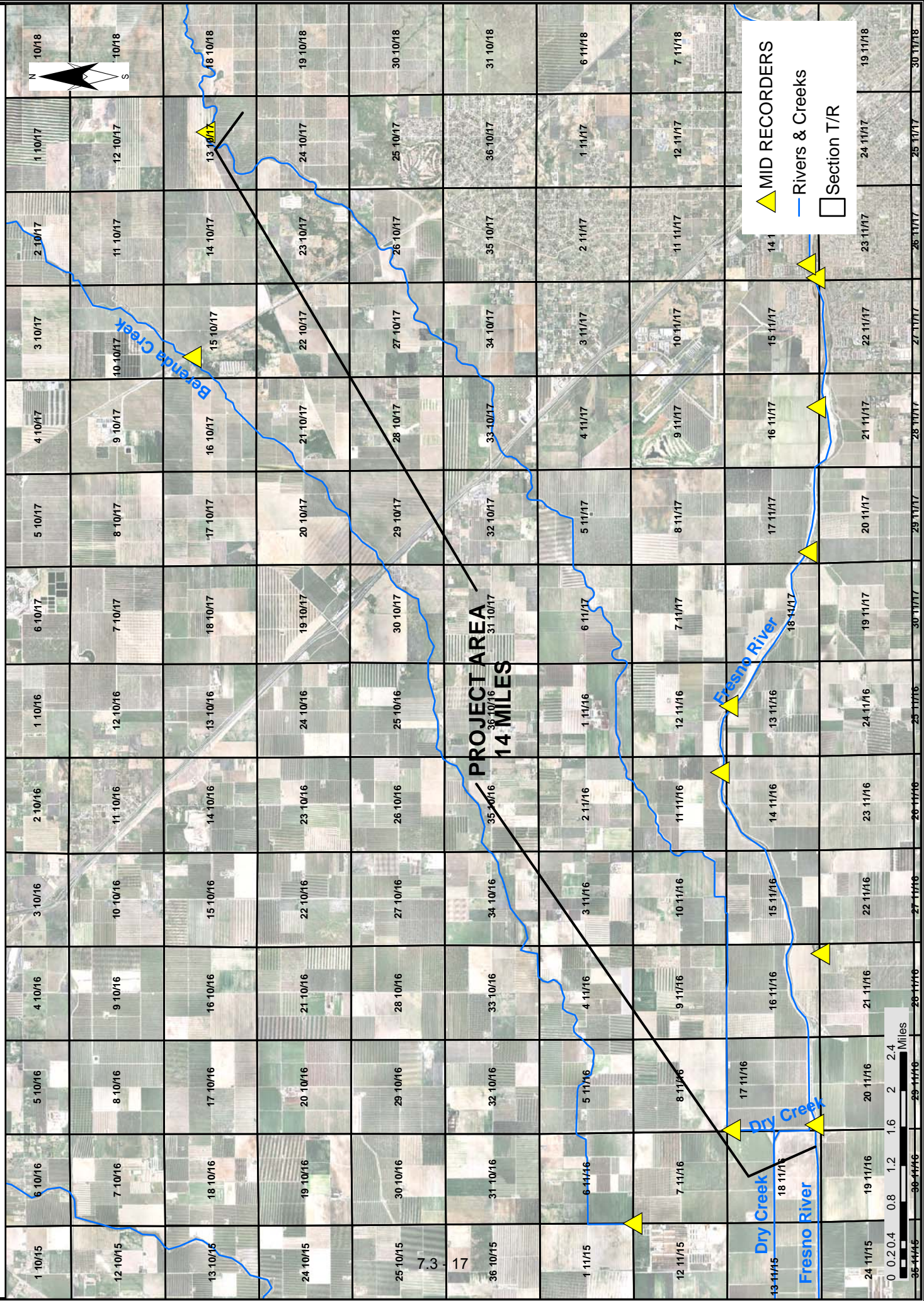
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# DRY CREEK ARUNDO LOCATION MAP



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# DRY CREEK RECORDER LOCATION MAP



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**Attachment 7.3 - Preliminary Comparison of Transpirational Water Use  
by *Arundo donax* and Replacement Riparian Vegetation Types in  
California**

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## ***Preliminary Comparison of Transpirational Water Use by Arundo donax and Replacement Riparian Vegetation Types in California***

Report to Madera Co. RCD, Elissa Brown

From: Tom Dudley, Marine Science Institute, U.C. Santa Barbara  
& Shelly Cole, Environmental Sciences Program, U.C. Berkeley

### **Introduction**

*Arundo donax* or giant reed is hypothesized to cause excessive losses of groundwater to the atmosphere, based on an assumption that it has high transpiration rate during photosynthesis relative to other riparian plant types, and that its large leaf surface area facilitates even greater water consumption and transport (Dudley 2000). Some initial comparisons do suggest that it may transpire almost double the amount of water as does a native willow in northern California under some circumstances (Zimmerman 1999, Hendricks et al. 2006). Researchers in Texas indicate that *Arundo* has high transpiration output but associated plant types were not compared in that case (Watt et al. 2008). In semi-arid riparian areas of California and the Southwest excessive transpiration by invasive plants potentially exerts pressure on natural or managed ecosystems by exhausting surface water and depleting groundwater (Shafroth et al. 2005). Documentation of such effects would provide a solid basis for implementing control programs for invasive plants such as *Arundo* if it can be shown that replacement by native or other plants that transpire less water could enhance water availability for wildlife and human uses.

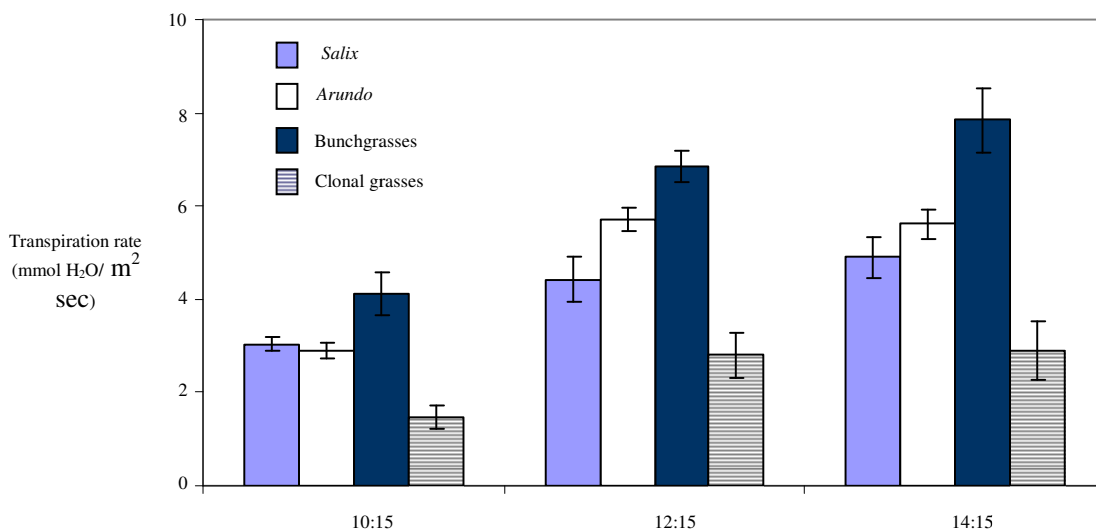
We conducted a comparison of water use by four vegetation types, including *Arundo*, a native willow, large-statured bunch grasses and prostrate, clonal grasses, to determine the relative amount of sub-surface water that are transpired to the atmosphere during the warm season in California. This trial study was conducted at the Hedrick Conservation Area (HCA), a private nature reserve on the Santa Clara River in Ventura County. *Arundo* and red willow (*Salix laevigata*) were plants that we had grown in an experimental 'plantation' for other ecological studies (Coffman 2006); the other plants were either installed in restoration efforts or existed naturally at the HCA within 200 meters of the plantation, and included 'bunch grasses' (*Leymus triticoides* – creeping wildrye, *Elymus condensatus* – giant wildrye) and 'clonal grasses' (*Distichlis spicata*, *Cynodon dactylon*). Weather data used for calculating moisture dynamics were from the nearby U.C. Coop. Extension Hansen Agricultural Center.

The trials were conducted at the beginning of September and consisted to 4 days for collecting data. Leaf-level moisture flux (transpiration) was measured using Lincoln Corporation portable photosynthesis unit (LiCor 6100) at three times of the day, mid-morning, mid-day and early afternoon, to reflect daily variation in temperature and light intensity. The LiCor test chamber would be used to measure moisture flux from two leaves on each test plant, the leaves chosen to be the uppermost (newest) on a given stem that had fully opened; measurements were replicated on a minimum of five plants for each treatment group (*Arundo*, *Salix*, bunchgrass, clonal grass). Whole plant transpiration was then estimated by extrapolating unit-leaf area moisture flux measurements to whole plant leaf area, which was determined by harvesting sub-portions of the test plants and measuring leaf dimension to calculate whole-plant leaf area.

### **Results**

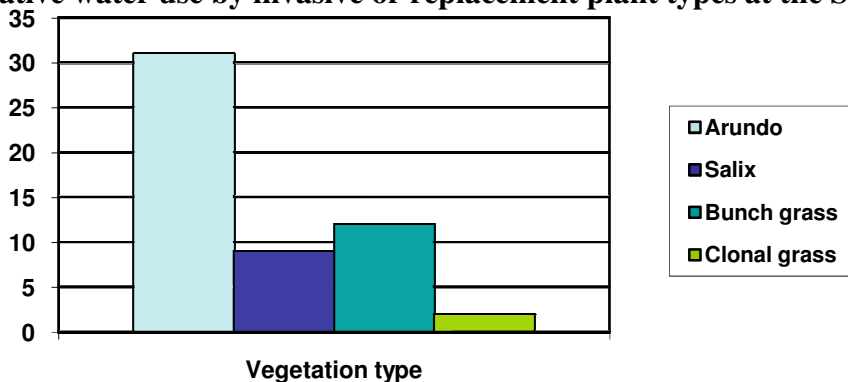
The following table presents values for transpiration (or water loss) through foliage of the experimental plants. These are estimates for a standardized leaf surface area, and indicate that generally willow (*Salix laevigata*) is roughly similar to *Arundo donax* on a leaf-area basis, that our ‘bunch grasses’ (*Leymus triticoides*, *Elymus condensatus*) are more water-consumptive, and ‘clonal grasses’ (*Distichlis spicata*, *Cynodon dactylon*) use substantially less water when standardized for leaf area. Note, however, that during the high light-intensity mid-day period, *Arundo* transpired approximately 25% more water than did the willow; these differences were statistically significant. This suggests that *Arundo* has an inherent higher capacity to continue transpiration (or photosynthesis) at a high rate when under excessive light conditions, while willows may respond to by reducing photosynthetic rate. Such photo-inhibition is well-documented in many plants, and it is likely that this dichotomy also exists between *Arundo* and willows too. This would translate into substantially larger daily ET rates for *Arundo*, once transpiration values are integrated over the full daylength period.

### Transpiration rates for target vegetation types at the Santa Clara River



The more critical comparison, however, is transpiration on a per-unit ground area basis. We calculated the photosynthetic area, or leaf area, for 4 plants of each plant type, as well as the average ground area occupied by that plant (its ‘footprint’). The estimated leaf area per m<sup>2</sup> for the four vegetation types at our study site on the Santa Clara River were: willow 1.1 – 2.9 m<sup>2</sup>; *Arundo* 3.7 – 6.7 m<sup>2</sup>; Clonal grasses 0.3 – 0.8 m<sup>2</sup>; Bunch grasses 1.0 – 2.4 m<sup>2</sup>. By using

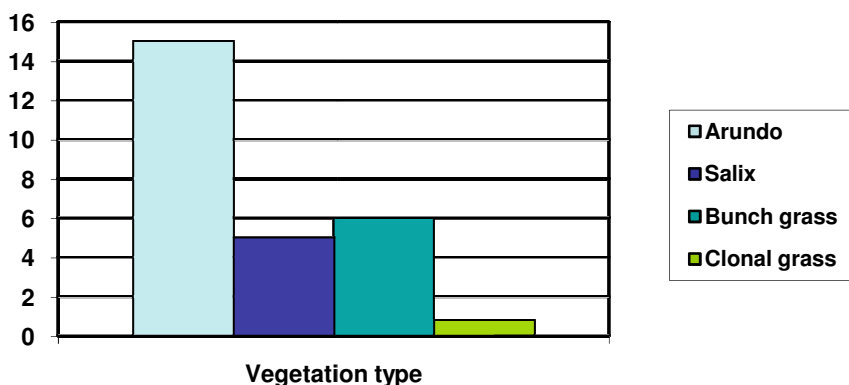
### Relative water use by invasive or replacement plant types at the Santa Clara River



the mid-range values for leaf-area, and the mid-day transpiration rates, the relative water use by these 4 vegetation types is: *Salix* – 9 units water (on a relative basis); *Arundo* – 31 units; Bunch grasses – 12 unit; Clonal grasses – 2 units water.

A rough prediction of the actual amount of water transpired to the atmosphere by each vegetation type can subsequently be calculated as the product of the transpiration volume per second over the time period that plants are photosynthetically active, and extrapolating this value to plant leaf area. For the late summer period when measurements were taken, we estimated the period of active photosynthesis as being 10 hours long (discounting morning and evening hours when light incidence is relatively low), and extrapolated interim hourly values between the three measurement points as a curvilinear relationship. This yielded a range of daily water use values from 0.015 m<sup>3</sup> (15 l.) per m<sup>2</sup> ground area with *Arundo* to 0.0008 m<sup>3</sup> (0.8 l.) for *Cynodon* and *Distichlis* clonal grass forms. That would be equivalent to 150 m<sup>3</sup> of water loss per hectare of *Arundo*-infested riparian area per warm, sunny day, or approximately 0.12 acre-feet per day.

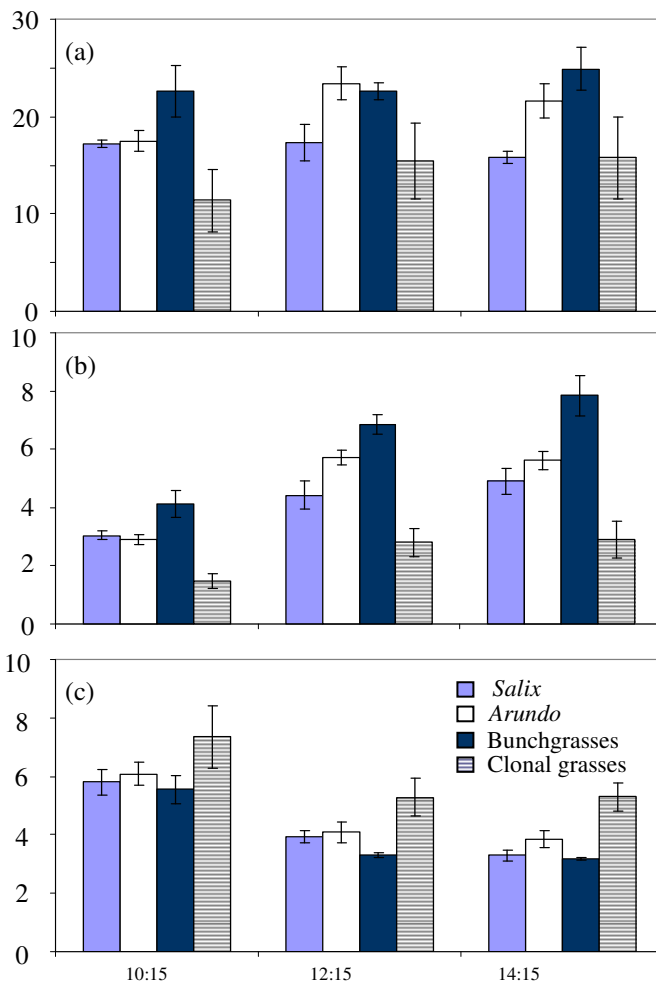
### Estimate daily mid-summer water use by target plant types (liters per day per m<sup>2</sup>)



These values could be further extrapolated to annual water use quantities by estimating the transpiration rates per unit time at different times of the year, but for several reasons this is beyond the scope of the preliminary data we have generated. For purposes of discussion, we might assume that these mid-summer transpiration values are representative of 4 warm months, that 4 spring and fall months produce half as much water use, and during winter there are 4 months of transpiration rates about 15% of summer rates. Based on these conjectures, *Arundo* may remove approx. 3.0 m<sup>3</sup> of groundwater to the atmosphere for every m<sup>2</sup> of infested land area, compared with 1.0 to 1.2 m<sup>3</sup> for native vegetation; 0.16 for groundcover ‘clonal’ grasses; this would be equivalent to drawing down the groundwater level by the same numerical relationship (e.g. 3 m by *Arundo*) if the whole system was comprised of that vegetation type. We cannot stand by these estimates, however, because transpiration is highly dependent upon air temperature and relative humidity, on water availability, and on the amount of total leaf area and shading that would exist at different times of the year. Although *Arundo* is presumed to be more metabolically active during winter months than are willows and so would certainly be relatively even more water-consumptive at that time of year, we are unable to make a rational evaluation of actual seasonal water use because of the lack of appropriate data needed to make such calculations.

The following graphs of PS rates and Water Use Efficiency expand the relationships described previously (the above Transpiration graph is ‘b’), although they are more complex than

is easily explained in this preliminary report. WUE suggests that the clonal grasses are most efficient at photosynthesis with respect to water used, while *Arundo* is marginally more efficient than the willows it has displaced.



The (a) photosynthetic rate ( $\mu\text{mol}/\text{m}^2 \text{ sec}$ ), (b) transpiration rate ( $\text{mmol}/\text{m}^2 \text{ sec}$ ) and (c) water use efficiency ( $\text{mmol CO}_2/\text{molH}_2\text{O}$ ) of study plants at three time periods.  $n=5$  and bars indicate  $\pm 1$  SE.

## Discussion/Preliminary Conclusions

It appears that under warm-season conditions in semi-arid regions *Arundo* uses roughly three times as much water as do moderate sized replacement species (red willow, ryegrasses) that also provide some habitat value for wildlife, and about 15 times more water than does a low-quality grass such as native saltgrass or introduced bermudagrass. This may translate to roughly 0.12 acre-feet of water use by an acre of *Arundo*-infested landscape, one-third that among by willows (0.04 ac-ft) and large grasses (0.05 ac-ft), and somewhat less than 0.01 acre-feet by low-growing native or exotic grasses.

One caveat is that there are certainly areas where *Salix* and other plants have a greater (or less) leaf surface area than we found at this site, so our results are not robust across a larger region without correction for the leaf area present per meter-square of land surface. We did, however, find roughly similar results when the same approach was taken in comparing *Arundo*

and *Salix exigua* in northern California (Zimmerman 1999). In that study, transpiration per unit leaf area was more equivalent between the two taxa, but the leaf area of *Arundo* was approximately double that of *Salix* so the water losses through *Arundo* were consequently about double that lost through willow photosynthesis.

It is important to note that these are very preliminary results, and firmer conclusions must wait until we do a longer series of PS/transpiration trials under a full range of environmental conditions, and at different times of the year. The degree of soil saturation greatly influences transpiration, and the plants in this study had ample water supplies available while under other circumstances plants may experience variable degrees of water-stress (and stress may differ among species) when results would be much lower. Also, these measurements were taken under full sunlight, but portions of plants obviously are shaded to different degrees, which will reduce photosynthesis, and thus, transpiration. The shade produced by *Arundo* may, in fact, be greater than that created by the other species which would further influence transpiration estimates. Plant density can further influence the local microenvironment, particularly by creating locally high humidity conditions which would also lead to over-estimates of water use by testing leaf surface transpiration in the open away from the plant under canopy, although the equipment can partially compensate for such humidity effects.

Also, we need to develop more accurate leaf area assessments, which will require much more extensive harvesting and measuring of plant parts. The stomatal surface area should be accurately described as well, because some plants have greater stomatal density on the same leaf surface area (even on one side vs. both sides of the leaf), which should be understood in accurately assessing water use. Some stems have photosynthetic tissue, which should be included in transpiration estimates.

In future studies we will determine how PS differs based on leaf types (new vs. old, sun vs. shade leaves) and at different positions in the plant. In particular, we intend to measure how shading affects leaf metabolic activity, but some very preliminary tests indicated that *Arundo* has higher PS activity in the shade than does *Salix*, which would certainly tend to increase the relative difference in water use by the two. That, in combination with estimates under low water availability levels, I think will certainly show that *Arundo* is very significantly and substantively worse than any of the other plant types, in terms of water loss from regional rivers and groundwater.

## Literature cited

Coffman, G..2007. Factors Influencing Invasion of Giant Reed (*Arundo donax*) in Riparian Ecosystems of Mediterranean-type Climate Regions. Doctoral dissertation, U.C. Los Angeles.

Hendricks, D.A., S. McGaugh, T. Dudley, K. Lyons. *Arundo donax* (Carrizo Grande / Giant Cane) in Cuatro Ciénegas. <http://www.desertfishes.org/cuatroc/organisms/non-native/Arundo/Arundo.html#Literature>

Shafroth, P.B., Cleverly, J.R., Dudley, T.L., Taylor, J.P., Van Riper, C., III, Weeks, E.P. & Stuart, J.N. (2005) Control of Tamarix in the Western United States: Implications for Water Salvage, Wildlife Use, and Riparian Restoration. Environmental Management, 35, 231-246.

Watts, D.A. G.W. Moore & K. Zhaurova. 2008. Ecohydrology and ecophysiology of *Arundo donax* (giant reed) in response to herbivory and drought. Entomol. Soc. America, 93<sup>rd</sup> annual meeting, Milwaukee, WI.

Zimmerman, P. (1999) Rates of transpiration by a native willow, *Salix exigua*, and by a non-native invasive, *Arundo donax*, in a riparian corridor of northern California. IN:Proceedings of the California Exotic Pest Plant Council. California Exotic Pest Plant Council, Sacramento, California